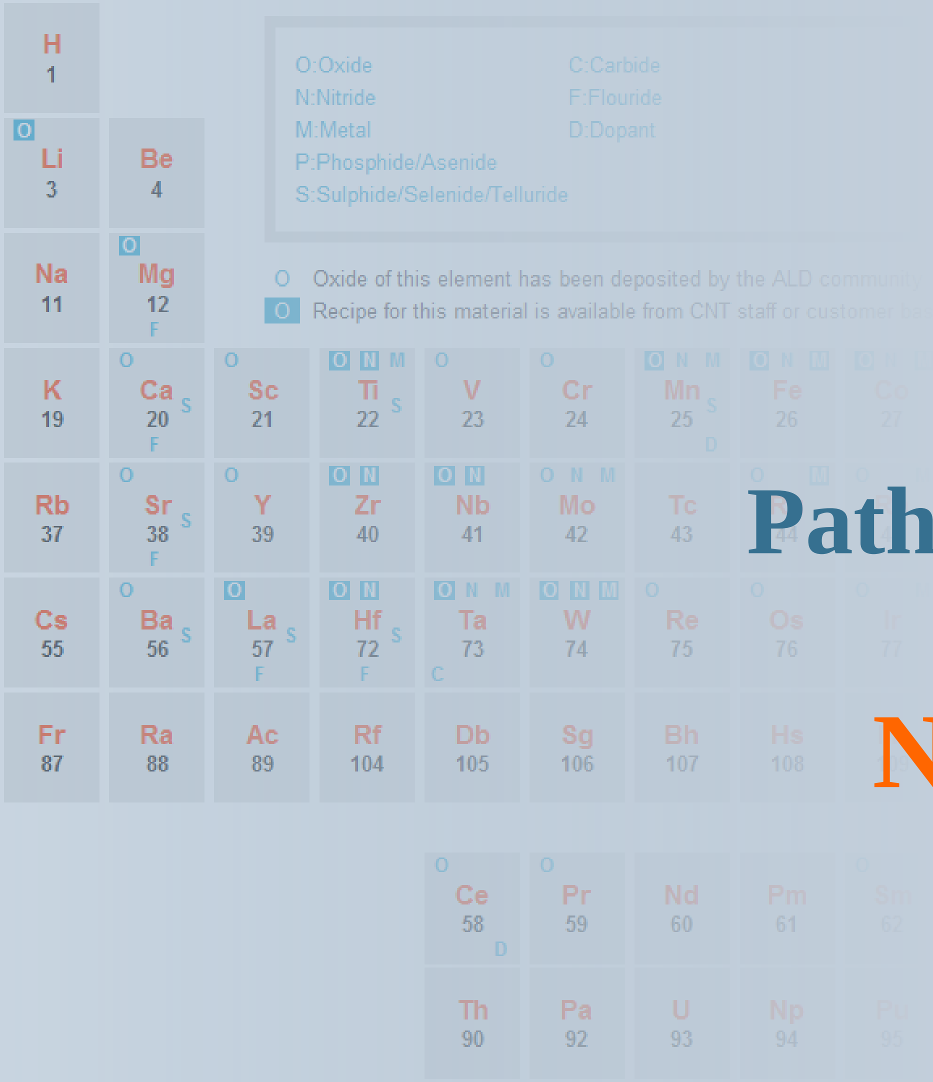


Lab to Fab: Path to Commercialization

Nanomanufacturing Summit

September 27, 2011

CambridgeNanoTech
Simply ALD

Agenda

- About Cambridge NanoTech
- Atomic Layer Deposition (ALD)
- Applications & Target Markets
- Product Portfolio
- Lab to Fab Strategy
- R&D Activities
- Future Products
- Summary

Cambridge NanoTech

- Founded in 2003
- Located in Cambridge, MA
- Grew directly out of Gordon Lab at Harvard University
- Dedicated to advancing the science and technology of ALD
- Multiple ALD product lines serving many applications and industries
- Rapid response to custom applications and projects
- Full staff of Ph.D. research scientists
- Strategic partnerships deliver complete ALD solution

SIGMA-ALDRICH STREM CHEMICALS, INC. MBRAUN Swagelok

Cambridge NanoTech Awards

March 2009 Boston Business Journal "Fastest Growing Private Company" Award

BBJ ranked No. 11 out of 2,500 fast-growing companies in Massachusetts with 416% growth 2005-2008

April 2009 Smaller Business Association of New England (SBANE) "Circle of Excellence" Award

Recognized for "transforming innovative ideas into a product service that delivers proven value to customers"

August 2009 Inc.5000 "Fastest Growing Companies"

Recognized for 401.1% growth from 2005-2008

Ranked No. 707 of 5,000 companies

Ranked No. 21 in Manufacturing and No. 27 overall in Boston region

May 2010 Boston Business Journal "Fastest Growing Private Company" Award

BBJ ranked No. 5 out of 2,500 fast-growing companies in Massachusetts with 234% growth 2006-2009

July 2010 SBANE (Smaller Business Association of New England) "Profitable Connections" Award

August 2010 Inc. Magazine's Inc. 5000 "Fastest Growing Companies"

Recognized for 401.1% growth from 2005-2008

Ranked No. 1303 of 5,000 companies

Ranked No. 21 in Manufacturing and No. 39 overall in Boston region

October 2010 Deloitte's 2010 Technology Fast 500

Ranked 154 of 500 companies around the nation

March 2011 Boston Business Journal "Fastest Growing Private Company" Award

BBJ ranked No. 8 of 55, recognized with 226% growth 2007-2010

May 2011 Women Presidents' Organization "50 Fastest Growing Women-Led Companies"

Ranked No. 19 of 50 companies

1962
ALD is invented by V.B. Aleskovskii

1974
ALD is patented by T. Suntola

2003
Dr. Jill Becker completes Harvard Ph.D. in Chemistry and founds Cambridge NanoTech

2004
First product, Savannah ALD research system is released

2005
Cambridge NanoTech sets sights on applying ALD principles to manufacturing tools

2005
Within first 24 months of release 50 Savannahs are sold

2007
Cambridge NanoTech starts building staff of in-house Ph.D. research scientists

2008
Phoenix batch production tool is released for manufacturing MEMs devices

2009
Fiji plasma ALD system is released

2009
Tahiti released for large area manufacturing of display technologies

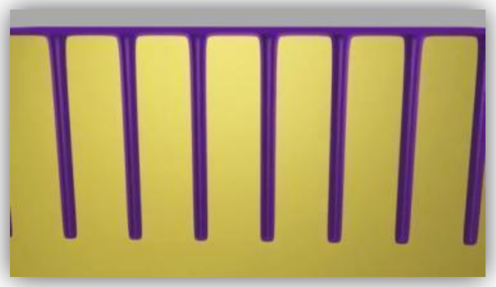
2010
Cambridge NanoTech develops large area ALD system for solar cell manufacturing

2011
Cambridge NanoTech now has over 250 research and production ALD systems in the field

Pioneering ALD Technology

Invented ALD Shield™ Vapor Trap

Developed Exposure Mode™ for Ultra High Aspect Ratio



Advancing the Science of ALD with in-house Research

Simplified ALD System Design

Scaled ALD to Production Technology

350+ Published Papers Feature Research Performed on Cambridge NanoTech Systems

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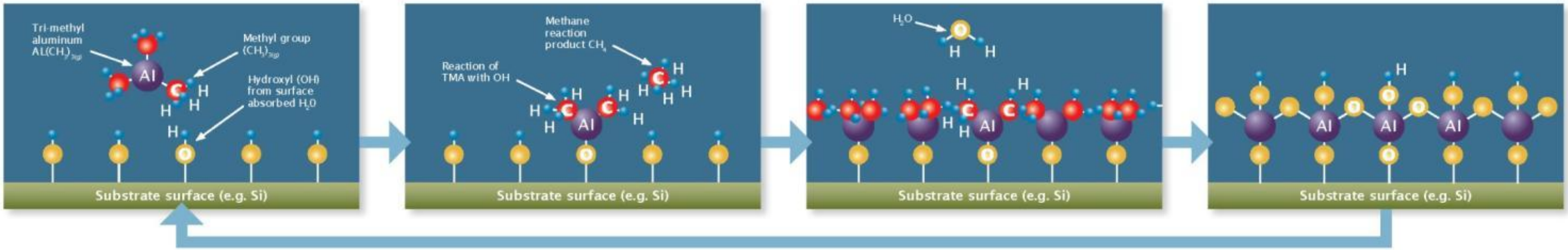
What is Atomic Layer Deposition?

Science of ALD

- A single ALD cycle consists of the following steps:
  - 1) Exposure of the first precursor
  - 2) Purge or evacuation of the reaction chamber to remove the non-reacted precursors and the gaseous reaction by-products
  - 3) Exposure of the second precursor – or another treatment to activate the surface again for the reaction of the first precursor
  - 4) Purge or evacuation of the reaction chamber
- A perfectly conformal, ultra-thin film is formed
- In the example below, precursors Trimethylaluminum (TMA) and H_2O are alternately pulsed to deposit an Aluminum Oxide (Al_2O_3) film



Benefits of ALD

- **Perfect films**
  - Digital control of film thickness
  - Excellent repeatability
  - 100% film density
  - Amorphous or crystalline films
- **Conformal Coating**
  - Perfect 3D conformality
  - Ultra high aspect ratio (>2,000:1)
  - Large area thickness uniformity
  - Atomically flat and smooth coating
- **Challenging Substrates**
  - Gentle deposition process for sensitive substrates
  - Low temperature and low stress
  - Excellent adhesion
  - Coats challenging substrates – even teflon

ALD: The Green Nanotechnology

- Less raw material required to grow films compared to other deposition methods
- Used to help produce sustainable energy products such as solar cells, batteries
- Low temperature deposition assists in manufacturing of organic electronics
- Precise process yields low impurity = better product reliability and longer lifetime = less waste
- Environmental + human health applications; water purification and implantable medical devices

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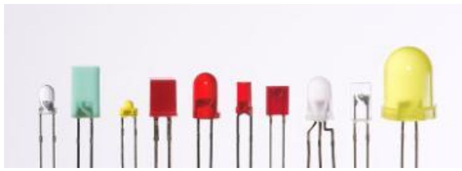
ALD Applications

Diversified Technologies & High Growth Markets

Lighting

OLED

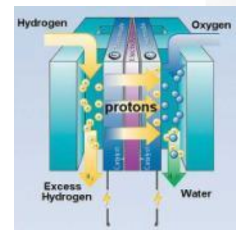


LED

Energy

Solar

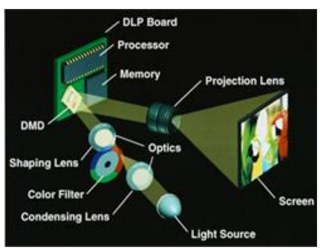
Li-ion Batteries



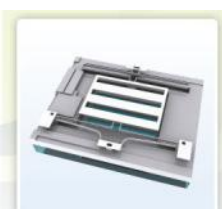
Fuel Cells

ALD Innovation and Market Focus

MEMS / Display



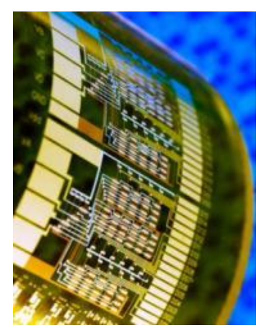
DLP MEMS Micro-mirror Display Technology

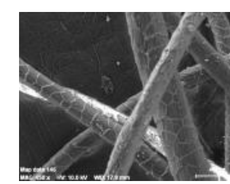


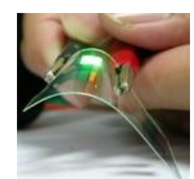
Digital Micro-Shutter (MEMS) Display Technology

MEMS Display Technology

Flexible Electronics/Textiles







Growth Strategy: Lab to Fab

1. Select high growth markets with diversified technologies where ALD can add unique value.
2. Align products and performance with key requirements for chosen markets and technologies.
3. Seed R&D labs or pilot production facilities of targeted companies with Cambridge NanoTech's R&D systems.
4. Work closely with target companies to successfully implement ALD technology.
5. Provide migration strategy for target companies to transition to Cambridge NanoTech's production systems.

Product Alignment to Target Markets

Target Market	R&D Systems	Production Systems	Products in Development
Energy	Savannah/Fiji	Phoenix / Tahiti II	*Particle ALD system
MEMS/Display	Savannah/Fiji	Phoenix/ Tahiti, Tahiti II	
Lighting	Savannah/Fiji	Phoenix, Tahiti	*Particle ALD System
Flexible Electronics/ Textiles	Savannah/Fiji	R2R (in dev.)	*Particle ALD system, R2R


Savannah


Fiji


Phoenix


Tahiti


Tahiti II

* Development of Particle ALD system to enhance existing particle coating capability.

2010 R&D Activities

Talks / Papers / Conferences

NIST Research Series
"An Introduction to the Principles and Applications of ALD"
G. Sundaram, A. Bertuch, R. Bhatia, M. Dalberth, E. Deguns, G. Liu, M. Sowa, and J. Becker

ALD 2010, Seoul Korea:
"Precursor Boost for Low vapor Pressure ALD Precursors"
G. Liu, A. Bertuch, M. Sowa, R. Bhatia, E. Deguns, M. Dalberth, G. Sundaram, and J. Becker

"Role of Process Conditions for Low Resistivity TiN via Plasma Enhanced ALD
M. Sowa, G. Liu, M. Dalberth, E. Deguns, R. Bhatia, G. Sundaram, and J. Becker

BALD 2010, Hamburg, Germany
"A Stable Organometallic Precursor for Nb_2O_5"
E. Deguns, R. Bhatia, J. Wozny, M. Dalberth, R. Kanjolia, D. Moser, G. Sundaram, and J. Becker

ECS 2010 Las Vegas, NV
"Fabrication of Coatings with Targeted Tunable Electrical Parameters via ALD: Al_2O_3/ZnO and Nb_2O_5/Ta_2O_5
A.Brodie, P. DeCecco, C. Bevis, J. Maldonado, R. Bhatia, E. Deguns, and G. Sundaram

"Plasma Enabled ALD of Niobium Nitride Using and Organometallic Nb Precursor"
E. Deguns, M. Sowa, M. Dalberth, R. Bhatia, R. Kanjolia, D. Moser, G. Sundaram, and J. Becker

"Large Format ALD Deposition"
G. Sundaram, A. Bertuch, R. Bhatia, R. Coutu, M. Dalberth, E. Deguns, G. Liu, M. Sowa, and J. Becker

"Properties of HfO_2 deposited with Ozone or Oxygen Plasma"
M. Dalberth, M. Sowa, R. Bhatia, A. Bertuch, E. Deguns, G. Liu, G. Sundaram, and J. Becker

AVS 2010 Albuquerque, NM
"Role of PEALD System Plasma Source Operation on Substrate Ion Bombardment and the Impact on HfO_2 and TiN Film Properties"
Mark J. Sowa, Ganesh M. Sundaram, Eric W. Deguns, Ritwik Bhatia, Mark J. Dalberth, Adam Bertuch, Guo Liu, and Jill S. Becker

Articles in Trade Journals
"Pushing the ALD Envelope"
M. Sowa, G. Sundaram, E. Deguns, R. Bhatia, M. Dalberth, G. Liu, and J. Becker
Ceramic Industry
Vol 160, No.5, May 2010

NIST

AVS Science and Technology of Materials, Interfaces, and Processing

ECS

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2010-2011 R&D Activities

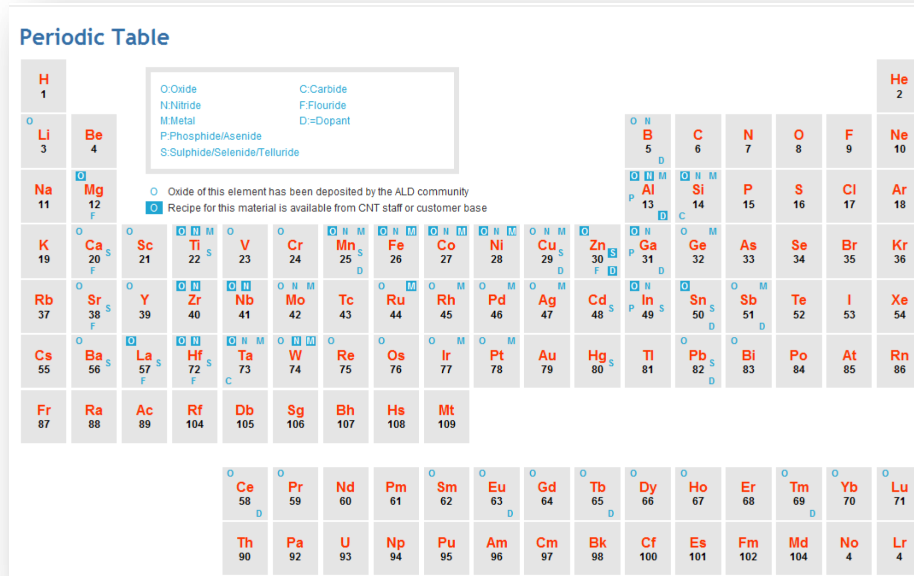
External Funding

- FlexTech Award for Development of RtR System ($1.0M spread over 2 years)
- SBIR (Phase1): Advanced Coatings for Flexible OLEDs ($100K for 6 months)
- Several Development Contracts: ~ $120K
  - $NbTaO_x$, ITO
  - ErOx, NbN
  - SAMs
- DOE Proposal for Catalysis Applications in Fuel Cells ($150K/year for 3 years)- Awaiting response.
- SBIR (Phase 1): Ice-o-phobic films ($100K) – Awaiting decision

2010-2011 R&D Activities

Films in Development

- Zn(OS)
- AlN
- SiO_2 (Thermal –new precursors)
- NbN (Plasma)
- $NbTaO_x$
- MgO
- WO_3
- TiO_2 (using TDMAT, instead of -isopropoxide)
- ITO
- NiO
- Ni
- SAMs (hydrophobic, hydrophillic, oleophobic films)
- Plasma SiO_2
- Plasma Pt
- Plasma ZnO
- Low resistivity plasma TiN



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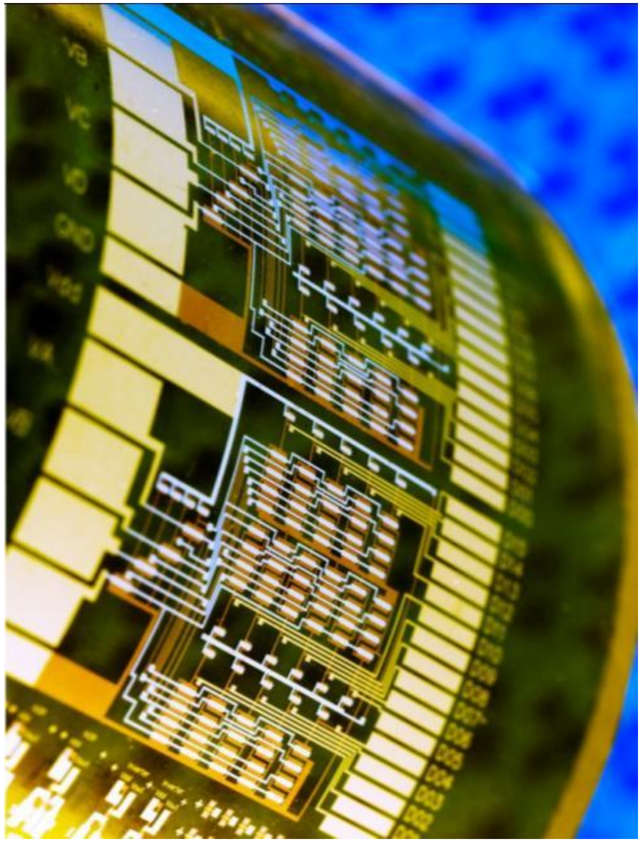
A Path to Roll to Roll ALD

- Zone Separated ALD
  - Based on the physical separation of pulses as opposed to the temporal separation of pulses.
  - Alleviates the major time component of temporal ALD- namely the purge time.
  - Compatible with R2R schemes
  - **Workshop on Nanofabrication Technologies for Roll-to-Roll Processing Sept 28th**



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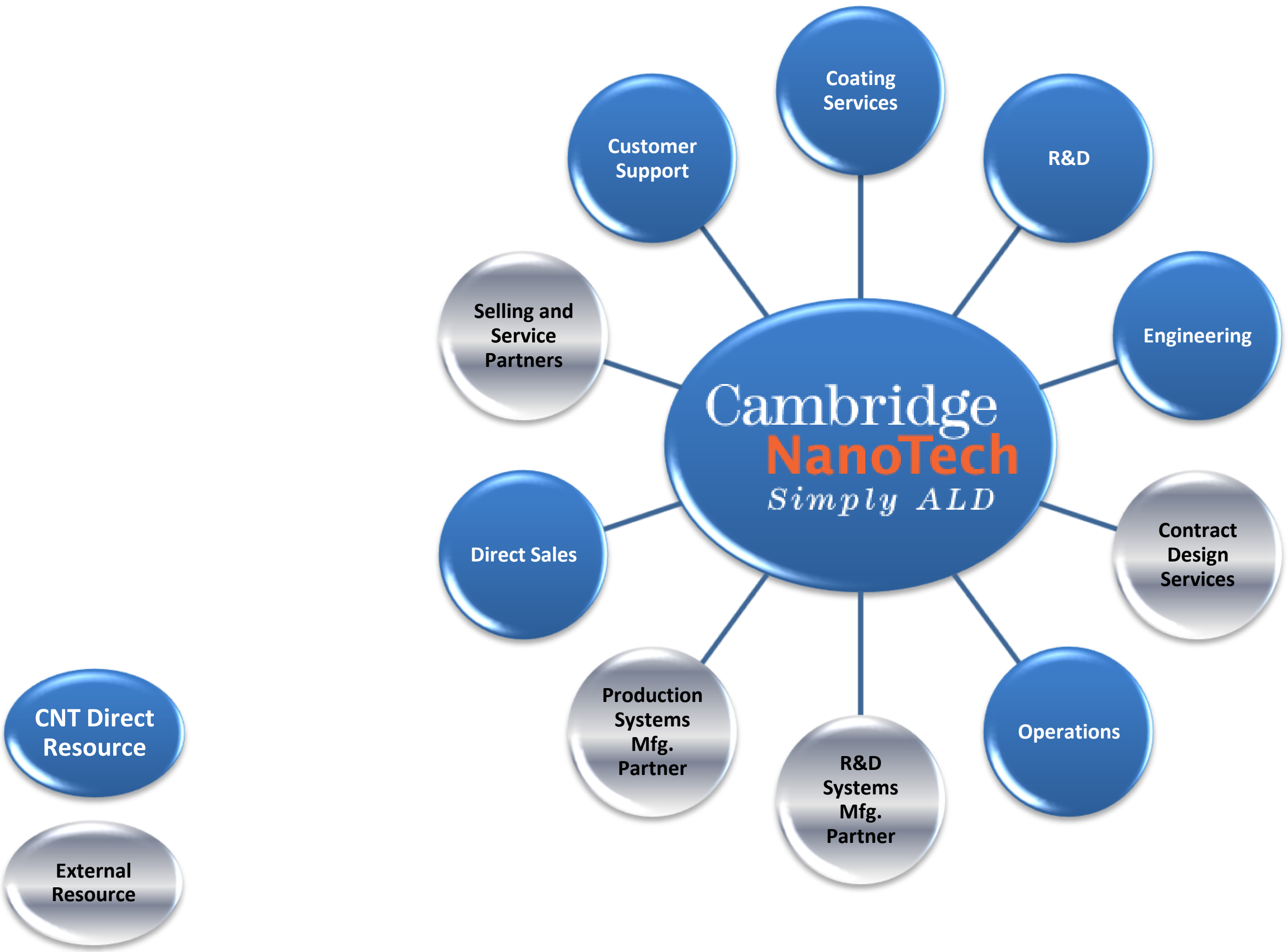
Maximizing Our Resources

Cambridge NanoTech strategically utilizes outside resources to maximize product and process offerings



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www.cambridgenanotech.com

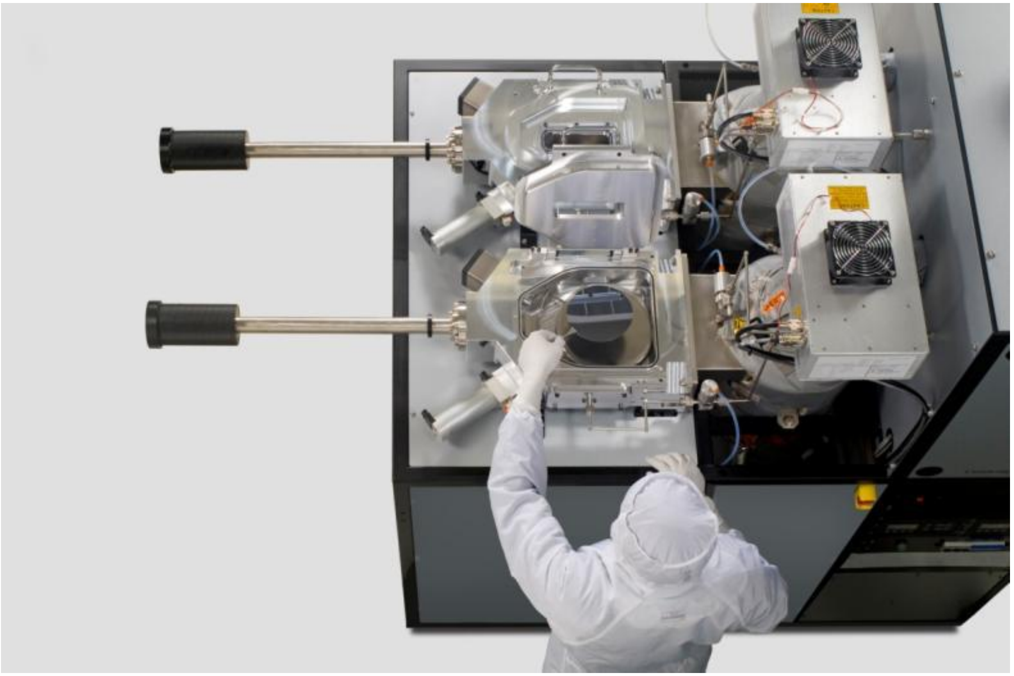
Cambridge NanoTech Sales and Support Locations

Selected Reference List

- Covidien
- DuPont
- Fujitsu
- General Electric
- General Motors
- Hewlett-Packard
- IBM
- KLA-Tencor
- Lockheed Martin
- Northrup Grumman
- PerkinElmer
- Proctor & Gamble
- Schlumberger
- Texas Instruments

- Army Research Laboratory
- Case Western Reserve University
- Columbia University
- Cornell University
- Harvard University
- Georgia Institute of Technology
- Massachusetts Institute of Technology
- Max Planck Institute
- Naval Research Laboratory
- Northwestern University
- Princeton University
- Purdue University
- Sandia National Laboratories
- Stanford University
- Texas A&M
- Wright-Patterson Air Force Base

Cambridge NanoTech Team



Fiji F202 with Load Locks

Full staff of Ph.D scientists provides customers with:

- ALD applications support
- Research collaboration
- Recipe development
- Films development/characterization

Why Cambridge NanoTech?

Fiji F202 with Facade

- Cambridge NanoTech focuses exclusively on ALD providing tools for:
  - Research
  - Plasma Enhanced ALD
  - Batch manufacturing
  - Large area manufacturing
- Continual improvement to existing products and commitment to R&D for new products
- Partnerships with industry leaders provide our customers with a complete ALD solution
- Business model maximizes development effectiveness and global customer coverage

Thank You!

Market Snapshot: Solar

Technologies and Key Applications

- **Technologies:** Si PV, CIGS, DSSC
- **Problems:**
  1. Si PV requires passivation layer to slow carrier recombination, to improve efficiency
  2. CIGS requires a change from Cadmium based buffer (CdS) to alternate such as ZnOS due to toxicity of Cd
  3. DSSC require humidity barrier layer
- **Films Used**: Al_2O_3,(30nm) and ZnOS (20nm)

Sales

Total Available Market: $31.0B
Deposition Market Estimate: $1.1B

Execution of Strategy

Customer	Lab	Fab	Comments
Large Thin Film Manufacturer	**2x Tahiti II with additional Tahiti II planned**	**12-18 Tahiti II or more production systems**	**Transition to manufacturing expected to begin in 2012**
Large Si PV Manufacturer	**R&D Lab: Savannah S300**	**Phoenix**	**Early discussions about Phoenix have begun**
Japanese CIGS and Si PV Manufacturer	**R&D Lab: Fiji F200**	**Phoenix/Tahiti II**	**Early stage. Discussions will likely be around the Tahiti II**
Aoyama Gakuin Univ (CIGS, Si PV)	**Savannah S200**	**Japan Solar market Phoenix/Tahiti II**	**Prof. Nakada's leading solar research provides an extremely strong reference in the Japanese solar market**
DSSC Manufacturer	EPFL- Prof. Michael Graetzel: Savannah S200	Strong interest in a R2R prototype	Company is connected strongly to Prof. Graetzel, the inventor of the DSSC

Market Snapshot: Display

Technologies and Key Applications

- **Technologies:** IMOD, Digital Micro Shutter
- **Problems:**
  1. IMOD technology requires thin film 3D humidity barrier
  2. DMS technology requires thin film 3D humidity barrier
- **Films Used**: Al_2O_3 (8-50nm)

Sales

Total Available Market:	**248M TV units** **1.6B mobile phones**
Deposition Market Estimate:	**$2.3B**

Execution of Strategy

Customer	Lab	Fab	Comments
Large Display Manufacturer	**R&D Lab : Savannah S200, order for Fiji F200 expected in June**	**1x - Phoenix (Gen 2.5)** **6x –Tahiti (Gen 4.5)**	**Tahiti systems running production. Evaluating Tahiti II systems**
US Display Manufacturer	**R&D: Lab Savannah S200**	**Likely to be Tahiti II systems**	**Discussions have picked-up pace upon announcement of partnership with Hitachi Display, and Samsung as manufacturing partners**
Korean Display Manufacturer	**Coating Services**	**Phoenixes**	**Performed coating services**
Japanese Display Manufacturer		Tahiti II	Began initial meetings
Taiwanese Display Manufacturer		Tahiti II	Began initial meetings

Market Snapshot: Lighting

Technologies and Key Applications	Sales
• **Technologies: OLED, LED** • **Problems:** 1. OLED technologies require extremely stringent encapsulation layers to prevent O_2 and H_2O permeation 2. LED technologies require device level encapsulation, as well as encapsulation of LED phosphors to inhibit degradation. • **Films Used**: Al_2O_3, Al_2O_3/ZrO_2 nanolaminates (25-100nm)	**Total Available Market: $6B** **Deposition Market Estimate: $324M** **Leading Companies:**

Execution of Strategy

Customer	Lab	Fab	Comments
Taiwanese Display Manufacturer	R&D Lab: Phoenix (Glovebox)	Likely more Phoenix systems in glovebox configuration	Customer is expecting to initiate high volume manufacturing end of year.
Japanese LED Manufacturer	R&D Lab: Fiji F200	Likely Phoenixes. Inquiries for ALD particle coating system	Investigating several applications: standard encapsulation, phosphor coatings, and DUV LED electron blocking layers
US LED Manufacturer	R&D Lab: Coating services and development work		Developed ALD ITO. Initial discussions about Phoenix systems
German Lighting Manufacturer	R&D Lab: Savannah S300		System as functioned extremely well in R&D group. Investigating next phases

Market Snapshot: Flex Electronics/Textiles

Technologies and Key Applications

- **Technologies:** Polymer electronics flexible solar cells, displays and lighting. Performance textiles
- **Problems:**
  1. Humidity barrier for polymer based electronics -
  2. Humidity barriers for flexible displays and flexible OLEDs, and solar.
  3. Performance textiles: antibacterial, anti-stain, hypo-allergenic, and conductive properties
- **Films Used**: Al_2O_3 , ZnO (1-20nm)

Sales

Total Available Market: **$1.2B**
Deposition Market Estimate: **$65M**

Leading Companies:

Execution of Strategy

Customer	Lab	Fab	Comments
Japanese Consumer Products Manufacturer	**R&D Labs: Savannah S200**	**R2R system Completing Phase 1 at end of August 2011**	**Initial R&D work was sufficient to prepare a multi-phase program for insertion of ALD into manufacturing**
FlexTech Alliance: currently funding CNT through FlexTech Alliance Award	**Multiple Savannah S200s at alliance member facilities**	**Expected to take R2R units**	**Program review July 2011. Multiple discussion and visits by members to see R2R prototype and discussion on beta version of R2R unit**
DSSC Manufacturer	Strong connections with EPFL (Graetzel lab)		Have expressed interest in examining and purchasing R2R prototype unit
Textile Manufacturer			Began initial dialogue on performance textiles